The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed Andrew Gerry

Dated 5 December 2003

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
CD
2 1 MAY 2003
RECEIVED BY FAX

The Patent Office

1/77

22MAY03 E809756-1 010153
P01/7700 0.00-0311676.1

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference — P171-GB

2. Patent application number *(The Patent Office will fill in this part)* — 0311676.1 — 2 1 MAY 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

1... Limited
St John's Innovation Centre
Cowley Road
Cambridge CB4 0WS

Patents ADP number *(if you know it)* 8113870001

If the applicant is a corporate body, give the country/state of its incorporation — England

4. Title of the invention — CERAMIC ACTUATOR, METHOD OF MANUFACTURING AND USES THEREOF

5. Name of your agent *(if you have one)* — Akram K. Mirza

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

1... Limited
St John's Innovation Centre
Cowley Road
Cambridge CB4 0WS

8113870001

Patents ADP number *(if you know it)*

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

YES

Patents Form 1/77

0069609 21 May 03 08:58

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	0
Description	9
Claim (s)	2
Abstract	1
Drawing (s)	4

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 21-MAY-2003

12. Name and daytime telephone number of person to contact in the United Kingdom Akram K. Mirza 01223-422290

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.

d) If you have answered 'Yes' Patents Form 7/77 will need to be filed.

e) Once you have filled in the form you must remember to sign and date it.

f) For details of the fee and ways to pay please contact the Patent Office.

[redacted]71-GB

CERAMIC ACTUATOR, METHOD OF MANUFACTURING AND USES THEREOF

FIELD OF THE INVENTION

The present invention relates to novel electro-active actuators, their manufacturing and use in devices such as loudspeaker systems for portable electronic devices.

BACKGROUND OF THE INVENTION

It is known to construct a rotary device from a curved piezoelectric element shaped as arc around an axis. Such devices are for example described in the international published patent application WO-02/078053 and WO-03/001841.

In the commonly-owned published international patent application WO-03/001841, which is incorporated herein by reference, there are described various devices and methods to generate sound comprising a support on which is mounted an electro-active actuator, which is in turn coupled to an area-extensive section of the case of the device, which section of the case acts as the sound generating element of a loudspeaker. In embodiments illustrated therein the sound generating element is driven in operation by an electro-active actuator preferably acting upon an edge of the sound generating element. The actuator described is a flat ceramic bender curved into an almost tubular shape. This arcuate or C-shaped actuator generates a motion that is partly rotary in nature. For some applications, however, it is desirable to minimize the amount of rotary motion to the extend possible.

It is therefore the purpose of the present invention to provide an electro-active actuator capable of generating a

linear motion for use in devices such as loudspeakers for mobile phones etc.

SUMMARY OF THE INVENTION

Accordingly, in a first aspect the present invention provides a ceramic electro-active actuator comprising an arcuate middle section extending tangentially into two essentially straight end sections, similar to the shape of the letter "U".

The actuator is preferably cast or formed from one sheet of ceramic precursor material, such as "green tape". However at least every second of the electrodes required to pole or drive the actuator is discontinuous at the borders between adjacent sections. More preferably, both linear sections are electroded and poled in an essentially identical manner, whilst the center electrode is electroded and poled differently from the other sections.

In a preferred embodiment the length of the middle section equals essentially the combined length of the straight sections measured in tangential direction. The length referred to is the length of the active, i.e., electroded segment of a section, discounting other passive parts of the sections.

According to a second aspect of the invention, there is provided a method of manufacturing ceramic actuators comprising the step of preparing a three layer pre-cursor sheet with a continuous center electrode and two discontinuous outer electrodes with a layers of pre-cursor electro active material between adjacent electrode layers.

The discontinuous electrodes are preferable separated by non-conductive gaps at locations that correspond to the transition zones between the sections to be formed at a later forming step, thus being separated into two end and one middle segment.

a preferred variant of the method, an electrically conducting path is established between the end sections of one discontinuous electrode to the middle section of the other discontinuous electrode.

In a preferred embodiment of the method, the pre-cursor sheet is pressed in a mold and subsequently dried and sintered at elevated temperatures to render the pre-cursor material into electro-active material and to give the actuator the desired shape.

According to another aspect of the invention the actuator is used to drive a sound generating element in a portable device, preferably connected to a panel type diaphragm. The actuator is preferably mounted with one extended end section along an edge of the diaphragm with the opposite end being mounted on the housing of the device.

These and other features of the inventions will be apparent from the following detailed description of non-limitative examples making reference to the following drawings, throughout which like parts are designated by like reference numerals and characters.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1A is a perspective top view of an actuator in accordance with an example of the invention;

FIG. 1B shows a cross section through the actuator of FIG. 1A;

FIG. 1C shows a top view on the bottom face of the actuator of FIG. 1A;

FIG. 2 illustrates the bending deformation of the actuator of FIG. 1;

FIG. 3 illustrate a loudspeaker driven by an actuator as shown in FIG. 1is a perspective top view of another variant of the novel actuator;

FIG. 4 shows electrode layouts for use in a manufacturing process for an actuator in accordance with the invention; and

FIGs. 5A-C illustrate a tape forming process for use in a manufacturing process for an actuator sin accordance with the invention;

DETAILED DESCRIPTION

In FIG. 1, there is shown a perspective view (FIG. 1A), a cross-sectional view (FIG. 1B)and a top view on the bottom face (FIG. 1C) of the novel actuator **10** . The main elements of the actuator include a convex curved or arcuate middle section **11**. Both ends of the middle section **11** extend continuously in tangential direction into two essentially flat sections **12, 13**. The actuator **10** is manufactured from multi-layered ceramic tape **101** with layers of ceramic PZT

separated by layers of electrodes. The outer (visible) electrodes **102** are split at the transition zone between different section by gaps **103**. The flat section **13** forming the bottom face of the actuator carries further contact points. The contact points **104** provide conductive channels (via-fills) **105** to the center electrode **106** and the opposite outer electrode **102**, respectively. Placing the contact points **104** on the bottom face is advantageous when using surface mounting to mount the actuator on supporting structures such as PCB boards (see FIG. 3).

In FIG. 2 there is illustrated the deformation of the actuator **20** upon activation by an appropriate voltage applied to the electrodes. The actuator without activation is drawn using solid lines and dashed lines are used to depict the energized actuator. It should be noted that the deformation is drawn out of scale.

Upon activation, the ends of the c-shaped center section **21** perform a rotational movement with a slight contraction around its center of curvature as indicated by the arrows **24**, **25**. The extended straight sections **22**, **23** bend as conventional benders. The distal ends **221**, **231** of the actuator perform a very good approximation of a linear motion in vertical direction as indicated by the arrow **26**.

In FIG. 3, the actuator of FIG. 1 is shown used as a drive unit **30** to drive a rectangular diaphragm **34** within the housing **35** of a mobile device. The diaphragm is made of transparent polycarbonate. It rests within a recess of the housing so as to be mounted flush with its outer surface.

The gap between the housing **35** and the diaphragm **34** is sealed off by means of a compliant gasket **36**. The gasket **36** prevents the entry of dust or humidity. It is made of Poron (TM), a cellular urethane based sealing material.

The actuator **30** bridges is surface mounted with a first distal end **301** of the bottom straight section onto a PCB board **31** that carries drive electronics, power supply and other electronic circuitry. The end **302** of the top straight section of the actuator **30** is connected to an edge of the diaphragm **34** via a spacer element **32**. The connection is capable of transmitting a force such that in operation the vertical movement of the actuator **30** drives the edge of the diaphragm **34** which in turn generates audible sound.

The effective length of the straight sections is in part determined by the length over which these section are mounted or connected to spacer element or support. These part of the sections become too stiff to deform as a bender. When considering the active length of a section these parts have to be discounted.

Compared to known devices such as described in WO-03/001841, the novel configuration provides an improved sound quality.

The novel actuator can be manufactured from ceramic tape material made in accordance with know techniques as described for example by D. Pearce et al in Sensors and Actuators A 100 (2002), 281-286. The components such as PZT powder, binder and solvant are mixed, milled and pressed into flat sheets of the desired thickness.

The electrodes are screen printed onto the sheet using platinum or silver ink. A specific electrode layout may be used that facilitates the manufacturing and mounting of the novel actuators. This layout is shown in FIG. 4 which depicts the outer, center and inner electrode layer of an actuator with two PZT layers (as shown in FIG. 1).

The outer electrode **41** and the inner electrode **43** which on the actuator will both form outer visible electrodes are split by lines **44** into sections which correspond to the sections to be seen on the finished actuator. The center electrode **42** is continuous but includes smaller blank areas **45**. Cross-layer electrical contacts are made at a later stage either through (using a via-fill) or across the outer edges of the areas **45**(using conductive ink or solder). With the electrode pattern and blank areas it is possible to connect electrodes such that an electrically conducting path is established between the end sections of one discontinuous electrode **41** to the middle section of the other discontinuous electrode **43** bypassing the continuous electrode **42**.

Hence, in the finished actuator as shown in FIG. 1, the end sections of the outer visible electrode lie on the same potential as the middle section of the inner visible electrode and the end sections of the inner visible electrode lie on the same potential as the middle section of the outer visible electrode. In this configuration, the center electrode is not connected to any section of the outer electrodes.

Two or more printed sheets are then stacked to form a final bimorph tape. The bimorph ("green") tape is still plastically deformable.

A further processing step towards the novel actuator is shown in FIG. 5. In the forming step of FIG. 5, the green tape **50** is placed between the moving part **51** and stationary part **52** of a former or mold (FIG. 5A). The moving part **51** is then pressed downwards into the opening of the stationary part **52** thereby forcing the tape into the desired shape (FIG. 5B). In its final position (FIG. 5C), the moving part **52** has pushed the tape fully into the U-shaped mold.

It is worth noticing that the outer contour of the moving part **51** matches the inner contour of the stationary part **52** along the bottom section of the mold essentially corresponding to the curved center section of the finished actuator. However above this section the cross-section of the moving part tapers away from the walls of the mold 51, thus facilitating the removal of the moving part without pushing the tape out of its final position or form.

The tape can be left drying in the former and then removed from it. Then the tape is burned out and sintered at high temperatures (600 to 1200 degrees Celsius). Outer electrodes may be applied after the sintering step.

In a poling step the straight sections (as referred to in FIG. 1) are poled in a direction opposite to the poling direction in the center section.

After the poling the actuator is ready to be mounted onto a

support and a driving voltage can be applied for example to the center electrode.

[redacted]71-GB

CLAIMS

1. Loudspeaker for audible sound comprising a sound emitting element mounted onto a support structure and at least one ceramic bender-type actuator being connected to said sound emitting element and a support, wherein the actuator comprises an arcuate middle section extending tangentially into two essentially straight end sections and wherein the sound emitting element is connected to an end portion of one of the straight section and the actuator is mounted with an end portion of the other straight section onto the support.

2. The loudspeaker of claim 1 having a compliant sealing element or elements around the edges of the sound-emitting element.

3. The loudspeaker of claim 1 wherein sound emitting element is a flat or slightly curved transparent panel.

4. The loudspeaker of claim 1 wherein the support structure and the sound generating element are parts of the outer shell of a portable data handling or communication device.

5. Ceramic actuator comprising an arcuate middle section extending tangentially into two essentially straight end sections.

6. The ceramic actuator of claim 5 wherein the two essentially straight sections are parallel to each

other.

7. The ceramic actuator of claim 5 having an essentially -shaped cross-section.

8. The ceramic actuator of claim 5 wherein the straight sections are poled in a direction opposite to the poling direction of arcuate section.

9. The ceramic actuator of claim 5 formed from a continuous sheet of piezoelectric material.

10. Method for manufacturing an actuator in accordance with claim 5, comprising the steps of
- manufacturing deformable sheets of pre-cursor material;
- applying a first, a second and a third electrode onto the sheets;
- stacking said sheets such that at least one first, second and third electrode overlay to form a layer of bimorph tape;
- pressing the bimorph tape into the shape of the actuator; and
sintering the shaped tape, wherein two of the three electrodes have gaps at locations corresponding to areas between adjacent sections of the actuator and one of the three electrode is continuous across the areas.

11. The method of claim 10, further comprising the step of poling straight sections of the actuator opposite to the arcuate section.

ABSTRACT

A loudspeaker for audible sound and a drive unit are described having a sound-emitting element mounted onto a support structure and a U-shaped ceramic actuator made of piezoelectric material.

PI71 GB

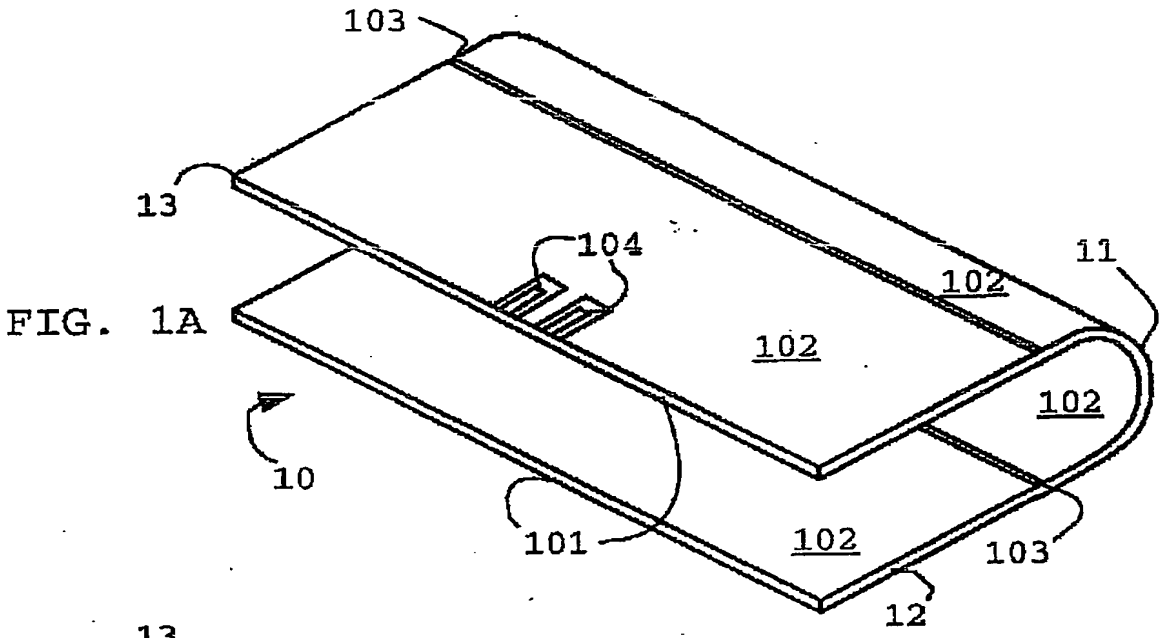

FIG. 1A

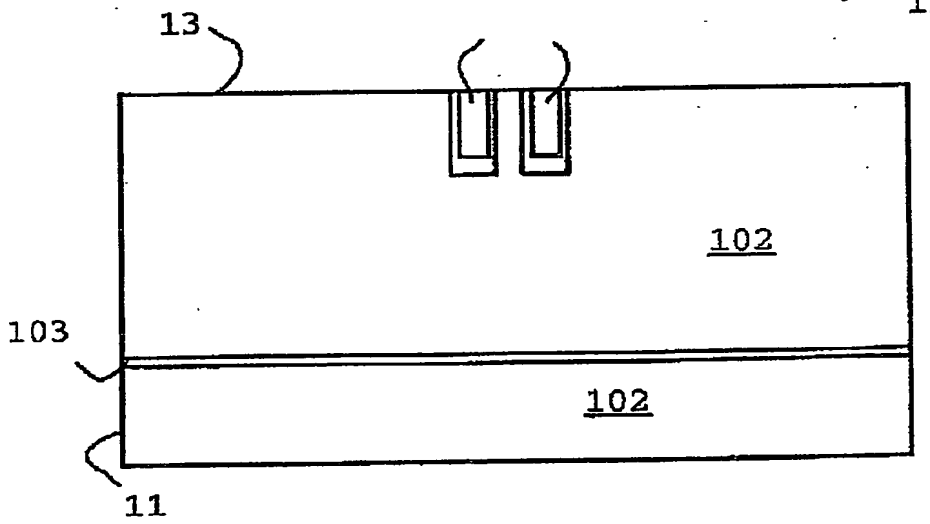

FIG. 1B

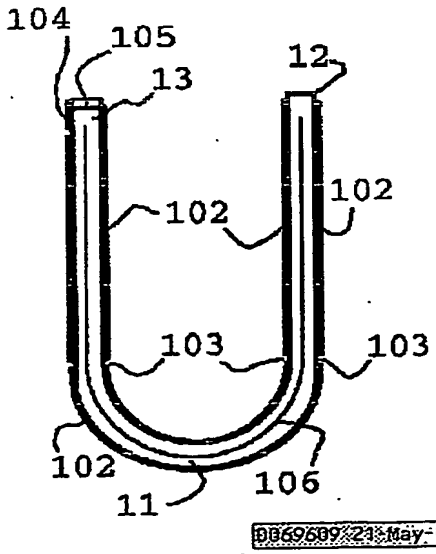

FIG. 1C

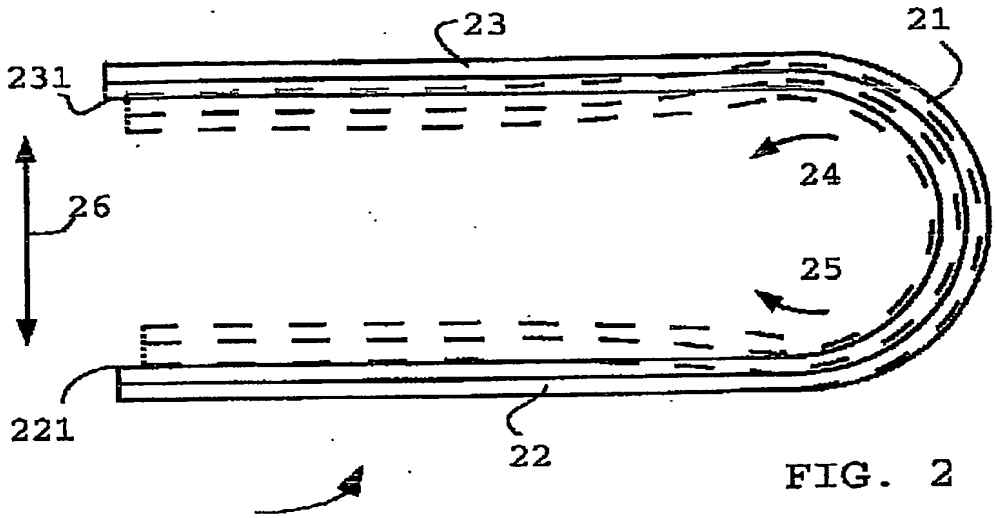

FIG. 2

FIG. 3

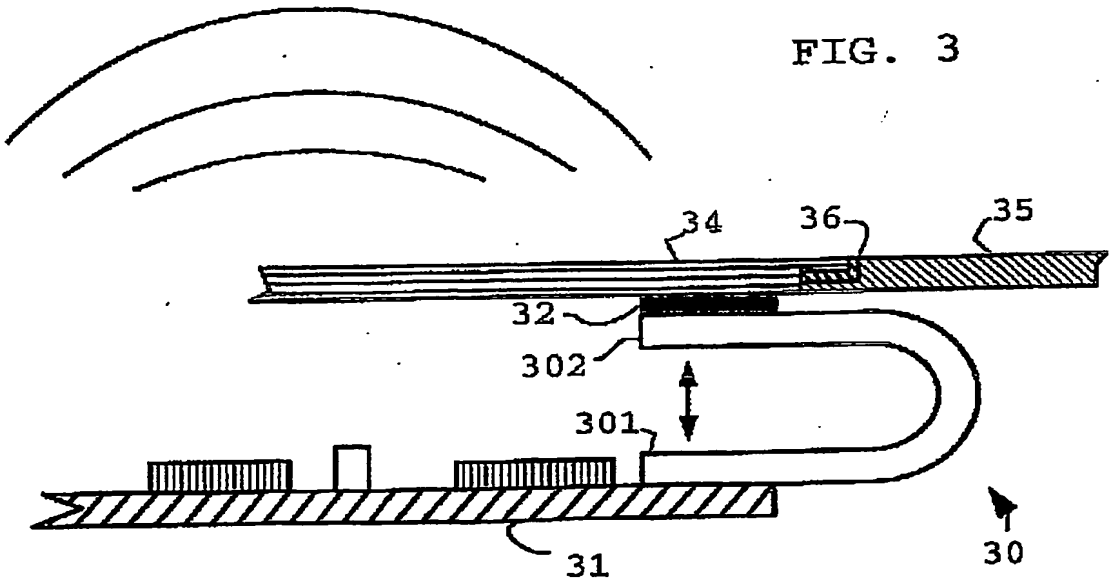

FIG. 1B

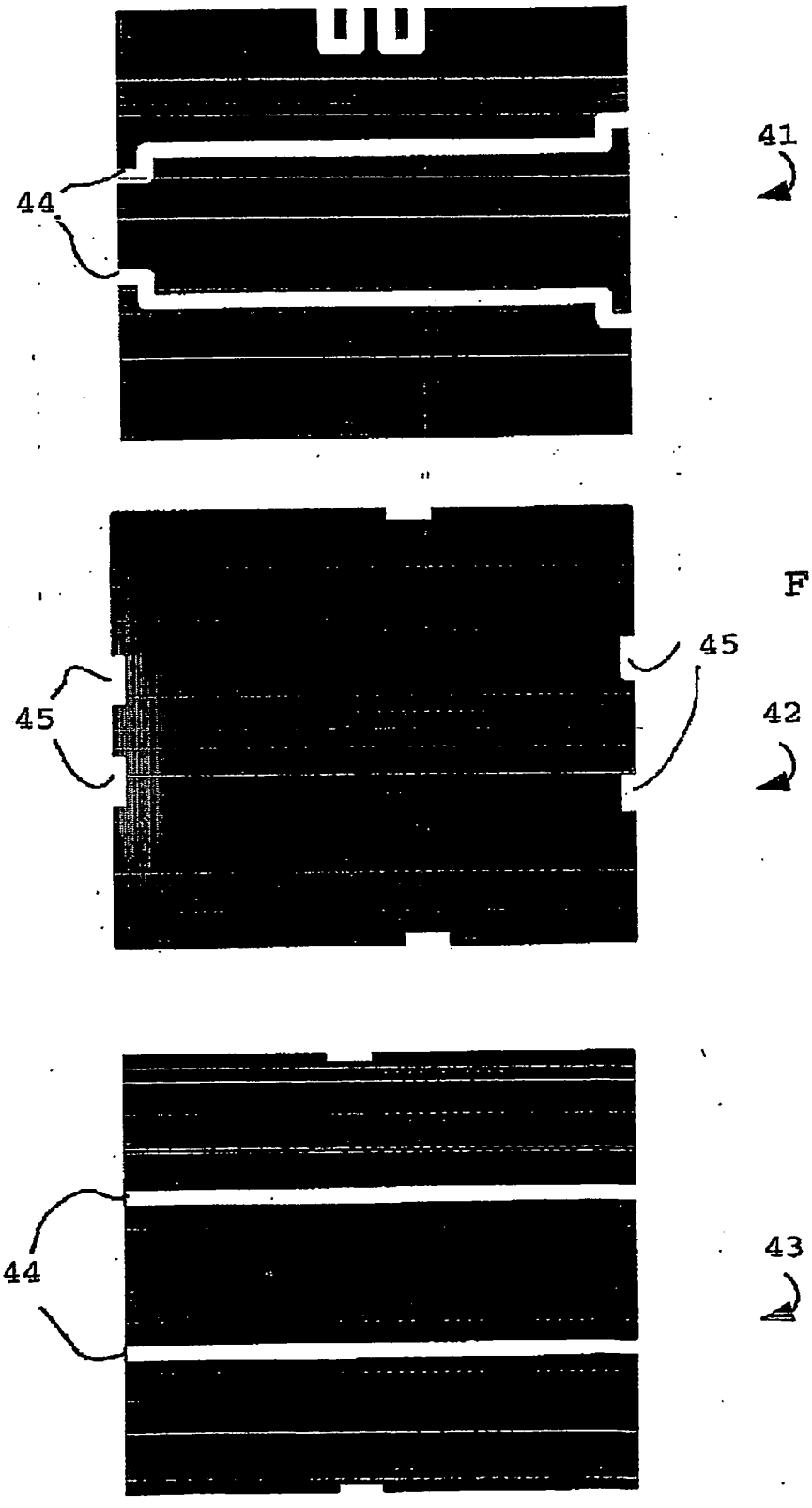

FIG. 4

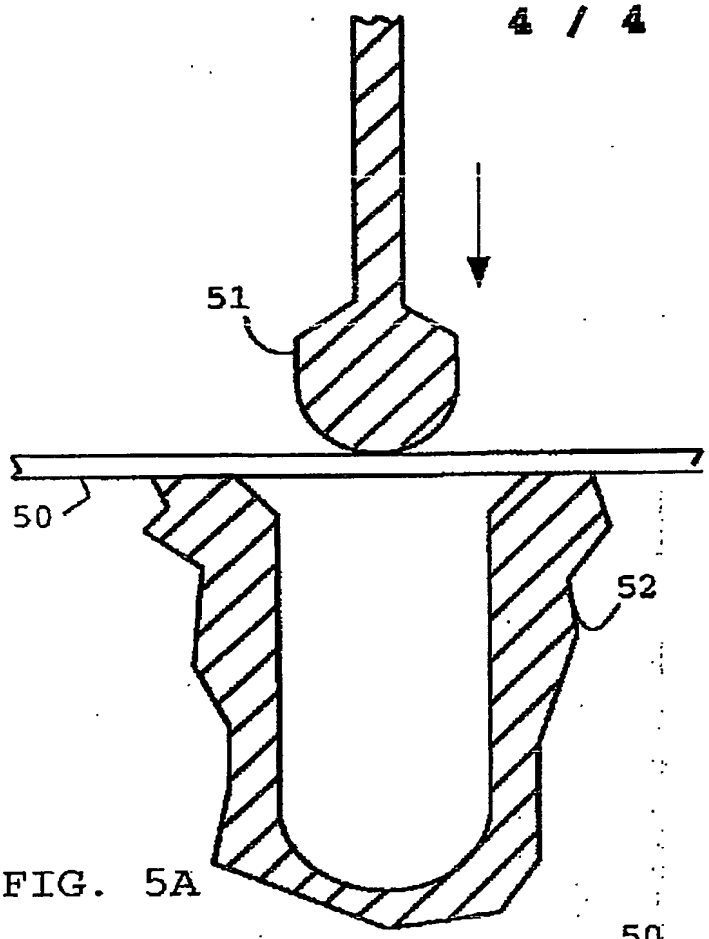

FIG. 5A

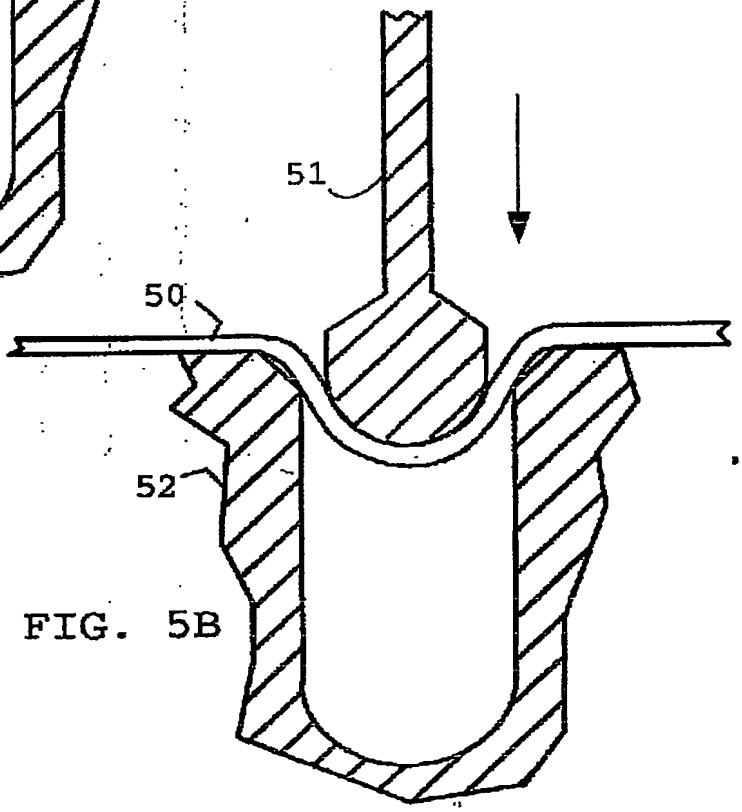

FIG. 5B

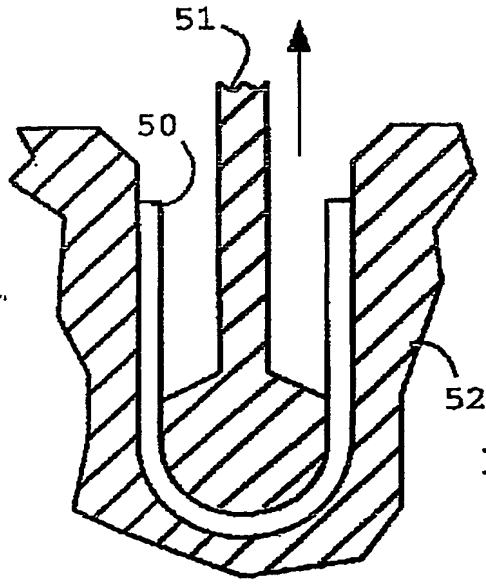

FIG. 5C

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☑ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☑ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.